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THESIS

EQUITABLY DISTRIBUTING QUALITY OF MARINE SECURITY GUARDS USING INTEGER PROGRAMMING

by

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March 2013

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Established through the Marine Security Guard (MSG) Program during the 1940s, the Marine Corps and Department of State have shared a partnership of providing critical security to designated diplomatic facilities worldwide. Approximately 250 Marines execute permanent change-of-station orders within the program five times every year to support personnel manning requirements. Are these Marines being sent to the right location? Is one embassy unintentionally staffed with a disproportionate quality of MSGs? Is there a better metric to measure and assign Marines based on a decision-maker's preference? The current assignment process is manpower-intensive and involves more than 15 personnel across three levels of command. At present, there is no formal methodology to quantify or measure how well MSGs are being assigned. The purpose of this research is to provide Marine Corps Embassy Security Group (MCESG) Headquarters senior leaders with an alternative method to complement the current assignment process by equitably distributing the quality of MSGs using integer programming. The results of this research support an improvement by up to 96% of distributing quality using the sum of squared differences across each region. The impact of using these alternative methods can be expected to significantly decrease MCESG assignment man-hours.

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EQUITABLY DISTRIBUTING QUALITY OF MARINE SECURITY GUARDS USING INTEGER PROGRAMMING

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Established through the Marine Security Guard (MSG) Program during the 1940s, the Marine Corps and Department of State have shared a partnership of providing critical security to designated diplomatic facilities worldwide. Approximately 250 Marines execute permanent change-of-station orders within the program five times every year to support personnel manning requirements. Are these Marines being sent to the right location? Is one embassy unintentionally staffed with a disproportionate quality of MSGs? Is there a better metric to measure and assign Marines based on a decision-maker's preference? The current assignment process is manpower-intensive and involves more than 15 personnel across three levels of command. At present, there is no formal methodology to quantify or measure how well MSGs are being assigned. The purpose of this research is to provide Marine Corps Embassy Security Group (MCESG) Headquarters senior leaders with an alternative method to complement the current assignment process by equitably distributing the quality of MSGs using integer programming. The results of this research support an improvement by up to 96% of distributing quality using the sum of squared differences across each region. The impact of using these alternative methods can be expected to significantly decrease MCESG assignment man-hours.

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LIST OF ACRONYMS AND ABBREVIATIONS

AQ	Average Quality
ARB	Accountability Review Board
BALMOD	Balance Model Formulation
COM	Chief of Mission
DoD	Department of Defense
DoS	Department of State
E	Enlisted
HAF	Headquarters Air Force
HQ	Headquarters
IO	Inspecting Officer
IP	Integer Programming
IQ	Individual Quality
LP	Linear Programming
MOS	Military Occupational Specialty
MCESG	Marine Corps Embassy Security Group
MSG	Marine Security Guard
MSGAT	Marine Security Guard Assignment Tool
NLP	Nonlinear Programming
NMC	Non-Mission Capable
OSAB	Operations Assignments Branch
PCS	Permanent Change of Station
PP&O	Plans, Policy, and Organization
Q	Quality
RSO	Regional Security Officer
SAI	Semi-Annual Inspection
SD	Standard Deviation
SE	Standard Error
SNCO	Staff Non-Commissioned Officer
T-ODP	Transitional Officer Development Plan

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This thesis is dedicated to the Marines, sailors, and civilians assigned to Marine Corps Embassy Security Group and Diplomatic Security Service personnel in every capacity who honorably serve with and support the Marine Security Guard Program. The efforts of this research are to ultimately support the Marine Security Guard watch stander who serves a critical role in protecting our national interest abroad.

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I. INTRODUCTION

For the past 60 years, the United States Marine Corps and the Department of State (DoS) have shared a partnership of providing critical security to designated diplomatic facilities worldwide. The partnership established through the Marine Security Guard (MSG) Program continues to expand and evolve to support the increasing demands for Marines required at additional embassies and consulates around the world. Approximately 250 Marines execute permanent change of station (PCS) orders within the program five times every year to support personnel manning requirements. The current assignment process is manpower-intensive and involves more than 15 personnel across three levels of command. There is no current methodology to quantify or measure how well MSGs are being assigned. Filling billets based on rank and experience does not sufficiently address the requirement to position a security force to meet operational requirements. Lastly, the tragic events that occurred at the U.S. Consulate in Benghazi, Libya, on September 11, 2012, add an additional strain on the current assignment process.

The purpose of this research is to provide Marine Corps Embassy Security Group (MCESG) Headquarters (HQ) senior leaders with alternative methods for equitably distributing the quality of MSGs.

A. SEPTEMBER 11, 2012, TERRORIST ATTACK ON U.S. CONSULATE IN BENGHAZI, LIBYA

An Accountability Review Board (ARB) was convened by then Secretary of State Hillary Rodham Clinton to review, analyze, and examine the events that surrounded the September 11, 2012, terrorist attack on U.S. Consulate Benghazi. The members of the ARB were selected by the Secretary and Director for National Intelligence and included Ambassador Thomas R. Pickering, Chairman; Admiral Michael Mullen, Vice Chairman; Catherine Bertini; Richard Shinnick; and Hugh Turner. As described in their report, the board members examined

> whether the attacks, were security related; whether security systems and procedures were adequate and implemented properly; the impact of

> intelligence and information availability; whether any other facts or circumstances in these cases may be relevant to appropriate security management of U.S. missions worldwide; and, finally, whether any U.S. government employee or contractor, as defined by the Act, breached her or his duty. (Bertini, Mullen, Pickering, Shinnick, & Turner, 2012, p. 1)

The ARB identified five findings and 11 recommendations. In summary, the findings ranged from a lack in security systems and procedures at the consulate and intelligence related issues overall with regard to the degrading situation in Libya, to systemic failures and leadership management deficiencies at senior levels within two bureaus of the State Department. The ARB categorized the recommendations into six core areas: Overarching Security Considerations; Staffing High Risk, High Threat Posts; Training and Awareness; Security and Fire Safety Equipment; Intelligence and Threat Analysis; and Personnel Accountability. "High Risk, High Threat" posts are defined by the ARB as posts in "countries with high to critical levels of political violence and terrorism, governments of weak capacity, and security platforms that fall well below established standards" (Bertini et al., 2012, p. 8). Security for personnel was listed as the first topic in the area of Overarching Security Considerations. The Board specifically stated that the "Department must strengthen security for personnel and platforms beyond traditional reliance on host government security support in high risk, high threat posts." A final recommendation listed by the ARB under Overarching Security Considerations was the acknowledgment of and support for increasing MSG presence at diplomatic facilities around the world. The following excerpt from ARB's report affects the Department of Defense (DoD).

> The Board supports the State Department's initiative to request additional Marines and expand the Marine Security Guard (MSG) Program–as well as corresponding requirements for staffing and funding. The Board also recommends that the State Department and DoD identify additional flexible MSG structures and request further resources for the Department and DoD to provide more capabilities and capacities at higher risk posts. (Bertini et al., 2012, p. 10)

B. MARINE SECURITY GUARD PROGRAM BACKGROUND

Regardless of location, MSGs have two basic missions that they perform under the operational direction and control of the facility's regional security officer (RSO) who reports directly to the chief of mission (COM).

> The primary mission of the Marine Security Guard (MSG) is to provide internal security at designated U.S. diplomatic and consular facilities in order to prevent the compromise of classified material vital to the national security of the United States. The secondary mission of the MSG is to provide protection for U.S. citizens and U.S government property located within designated U.S. diplomatic and consular premises during exigent circumstances (urgent temporary circumstances which require immediate aid or action). (U.S. Marine Corps, n.d.-b)

Additionally, a shared mission provided by the MSG Program and the White House Security Division is establishing executive services for designated personnel. MSGs frequently travel outside of their assigned country to support visits from very important persons (VIPs, such as the president, vice president, and secretary of state) with providing temporary protection of classified material at locations other than diplomatic facilities (e.g., in-country hotel).

The MCESG HQ is located in Quantico, VA, and is commanded by a Marine colonel. According to the MCESG website, its "mission is to exercise command, less operational control of the MSG's, in that it is responsible for their training, assignment, administration, logistics support, and discipline" (U.S. Marine Corps, n.d.-a). With a staff of approximately 100 Marines and civilians in Quantico, MCESG HQ provides the requisite administrative support to all Marines on the program who are forward deployed throughout the world. These administrative functions include but are not limited to assisting with personnel issues, conference planning, updating training and readiness standards, and serving as a focal point for communication with the DoS, White House Security Division for presidential visits, or Headquarters Marine Corps through the Plans, Policy, and Organization's (PP&O) branch at the Pentagon.

Subordinate to MCESG HQ are nine regional HQs numbered sequentially with different areas of responsibility. Each regional HQ has approximately 15 to 22 MSG detachments assigned to it. The breakdown of the nine regions is shown in Table 1.

Table 1. Marine Security Guard Region HQ Locations

Region	HQ Location	Area of Responsibility
1	Frankfurt, Germany	Eastern Europe and Eurasia
2	Abu Dhabi, United Arab Emirates	India and the Middle East
3	Bangkok, Thailand	East Asia and Pacific
4	Fort Lauderdale, Florida	South America
5	Frankfurt, Germany	Western Europe and Scandinavia
6	Pretoria, South Africa	East Africa
7	Frankfurt, Germany	North Africa and West Africa
8	Frankfurt, Germany	Central Europe
9	Fort Lauderdale, Florida	North America and the Caribbean

Each region HQ is commanded by a lieutenant colonel. The MCESG official website states that

> the mission of each is to exercise command, less operational supervision, of Marines assigned to the MSG detachments in their respective regions. The MCESG Region Headquarters ensures the continued training, operational readiness, personnel administration, logistical support, as well as the morale, welfare, and discipline of Marines assigned for duty to MSG detachments at designated U.S. diplomatic missions in order to support the DoS in the protection of classified material at foreign posts. U.S. Marine Corps, n.d.-b)

Not every diplomatic post has a MSG detachment. The decision to provide a detachment of Marines for a post is determined at the highest DoS level and is classified. However, the agreed number of detachments is negotiated between the DoS and DoD (via HQ Marine Corps). To date, there are 165 active detachments assigned globally to either a U.S. embassy or consulate in 141 different countries. Each MSG detachment is led by a Marine staff non-commissioned officer (SNCO) from the enlisted (E) pay grade rank beginning with staff sergeant (E-6) through master sergeant (E-8), and each with a complement of watch standers. Detachment commanders can be of any military occupational specialty (MOS). Watch standers range in rank from E-2 (lance corporal) through E-5 (sergeant), are unmarried, can be of any MOS, must qualify for a Top Secret clearance, and must pass the initial six-week MSG training conducted at Quantico. Each MSG detachment is comprised of a minimum of five MSG watch standers and up to 25, depending on the size and requirement of the diplomatic post. For example, the diplomatic mission in Canberra, Australia, is considered an average size post with an MSG detachment of five watch standers. MSG Detachment Canberra would be designated a 1/5 post. This would indicate one SNCO detachment commander and five watch standers. Comparatively, Baghdad, Iraq, would be considered a large detachment with a 2/25 post, indicating two SNCO detachment commanders (normally one more senior in rank than the other) and 25 watch standers.

C. CHANGES TO THE MARINE SECURITY GUARD PROGRAM

The recommendations of the ARB are translated formally into the National Defense Authorization Act for Fiscal Year 2013, which states that

> the Secretary of Defense shall develop and implement a plan which shall increase the number of Marine Corps personnel assigned to the Marine Corps Embassy Security Group at Quantico, Virginia and Marine Security Group Regional Commands and Marine Security Group detachments at United States missions around the world by up to 1,000 Marines during fiscal years 2014 through 2017. (S. 3254, 2012)

This increase in manning directly affects the responsibility of MCESG assignment personnel to ensure the right mix of Marines is assigned to the right location. .

D. WATCH STANDER ASSIGNMENT PROBLEM

The current process of assigning watch standers used by MCESG is iterative, very flexible and responsive. For example, assignment personnel can arbitrarily assign MSGs to new duty station location without regard to any billet restriction. There are five movement cycles during each fiscal year that correspond with the graduation of Marines from MSG School. The process begins approximately seven weeks before the movement cycle window opens. The opening of the movement cycle is designated as the first day Marines are authorized to execute PCS orders. Prior to the movement window opening, assignment personnel work closely with each of the region HQs to identify all watch standers who are either moving to another post or transferring off the program and other specific requirements associated with assigning personnel. A specific requirement could be, for example, whether a detachment within a region has an emerging requirement to be manned at 100%. MCESG assignment personnel then fill billets primarily based on the tenure and experience of watch standers remaining on the program, rank, and when possible, the preference location of individual Marines.

The inefficiencies of the current assignment process is that it is very subjective and man power intensive and requires several iterations of reviewing and updating assignment rosters that are exchanged among the region HQs. More than 15 personnel across three levels of command work closely with the MCESG assignment section to best fill billet requirements. This process is subject to delay due to time differences between region HQs spread throughout the world in different time zones and MCESG HQ. Last, there is no standard in the current process to measure the quality of MSGs assigned throughout the program. Due to the significant size of the population of movers during a movement cycle, approximately 250 Marines every cycle, it is difficult for assignment personnel to accurately capture and measure the quality of Marines being assigned. The assignment problem will be compounded with the authorized growth of the MSG program, and it will likely be even more difficult, if not impossible, for decision-makers to quantify the quality of MSG assignments. The methods provided in this research can be used to complement the current process by providing MCESG assignment personnel with a baseline that can be used as a starting point. From this point of reference, assignment personnel can coordinate more closely with each region HQ to finalize assignments. The focus can now be on filling detachment-level manning requirements instead of the time consuming effort of coordinating and manually tracking multiple spreadsheets.

II. LITERATURE REVIEW

Various types of mathematical programming models that can be used as an invaluable decision-making tool are reviewed in this chapter. Two related programming models were developed by Naval Postgraduate School students and are discussed because of their relevance to this research. Also, the concept of value-focused thinking proposed by Ralph Keeney (1992) is highlighted as an alternative approach to the traditional view of making decisions from a list of options.

A. LINEAR PROGRAMMING

Balakrishnan, Render, and Stair (2007) stated that "management decisions in many organizations involve trying to make the most effective use of resources" (p. 24). This statement is true for military organizations as well, since personnel are considered resources. Choosing where and when to commit these limited resources can become an arduous task, especially when the number of decision choices and alternatives increases. A decision-maker becomes even more conscious when the goal of a decision is to maximize profit for a company or to minimize any associated cost with certain actions. Examples of different types of problems are make-buy decisions, product mix problems, and transportation problems. Mathematical programming can be used to assist decision-makers with managing and solving potentially cumbersome problems. Within the broad topic of mathematical programming, the most widely used modeling technique desired to help managers in planning and decision-making is linear programming (LP; Balakrishnan et al., 2007). The Soviet mathematician A. N. Kolmogorov is recognized as the first person to conceptually develop the idea of LP. The use of LP has evolved since World War II when it was first conceptualized and is a significant resource tool for decision-makers in the commercial sector today. Balakrishnan et al. (2007) captured the three major steps in LP, which are formulation, solution, and interpretation and sensitivity analysis. Formulation is the first step of problem-framing and involves defining the problem or scenario into a simplistic, mathematical expression. This step includes defining the objective function, decision variables, and constraints for the situation as a whole. The solution step involves using the mathematical expressions developed in the first step and solving them either through the use of a mathematical program or graphically. The final step of LP is to review and analyze the results of the LP.

1. Transportation and Assignment Models

Balakrishnan et al. (2007) examined six different examples of special LP models, called network flow models: (a) transportation, (b) transshipment, (c) assignment, (d) maximal-flow, (e) shortest-path, and (f) minimal-spanning tree. Generally, these types of network flow problems all consist of nodes and arcs that connect together but are solved slightly different from each other. Balakrishnan et al. (2007) described when transportation models can be used, such as when a "firm is trying to decide where to locate a new facility" (p. 186). This decision may involve several alternatives where the goal is to minimize total production and transportation costs. Specifically, the "transportation model deals with the distribution of goods from several points of supply (called origins, or sources) to a number of points of demand (called destinations, or sinks)" (p. 186). The transportation problem usually involves capacity and requirement constraints at each of the different nodes or locations.

The assignment model is a slight variation to the transportation model. The concept is essentially the same, but this type of LP involves "determining the most efficient assignment of people to projects, salespeople to territories, contracts to bidders, jobs to machines, and so on" (Balakrishnan et al., 2007, p. 186). The goal for these types of problems can also be to either maximize or minimize some objective function. The slight variation compared to the transportation model is that "a job or worker can be assigned to at most one machine or project, and vice versa" (Balakrishnan et al., 2007, p. 186). Figure 1 is an example of a network flow model for an assignment problem. In this assignment problem, the Fix-It Shop must decide how to best assign workers to projects. Using the transportation model definitions, the nodes are represented by the workers (origin) and projects (destination), and the arcs are represented by the possible assignments connecting each of the six nodes. Given a list of associated labor costs for each worker, a potential LP problem could be to find the least-cost solution.

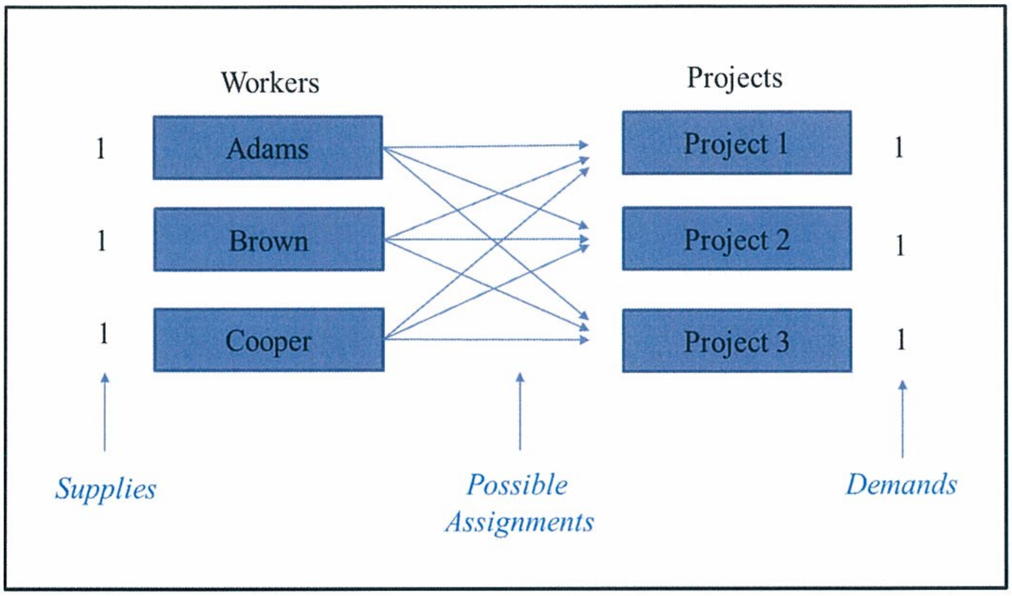


Figure 1. Network Model for Fix-It Shop–Assignment (From Balakrishnan et al., 2007).

2. Other Types of Programming Models

There are several other types of programming models used to solve more complex problems such as nonlinear, integer, goal, and quadratic programming. LP models and nonlinear programming (NLP) models are very similar in model development for both maximizing and minimizing an objective function. The problem is an NLP problem if the objective function is nonlinear or the feasible region is determined by nonlinear constraints (Bradley, Hax, & Magnanti, 1977). Integer programming (IP), on the other hand, provides decision-makers with integer values that may be more useful than fractional solutions. For example, if an airline company wanted to maximize profits by determining the best mix of economy and business class seats it should sell, a fractional value may not provide the best solution. Simply rounding the number to the nearest positive integer may overlook more optimal solutions. According to Balakrishnan et al. (2007), IP can take the form of general integer variables and binary variables.

General integer variables are variables that can take on any non-negative integer value that satisfies all the constraints in a model (e.g., five submarines, eight employees, 20 insurance policies). Binary variables are a special type of integer variables that can take on only either of two values, 0 or 1 (Balakrishnan et al., 2007, p. 238).

B. RELATED WORK

1. Optimizing Marine Corps Personnel Assignments Using an Integer Programming Model

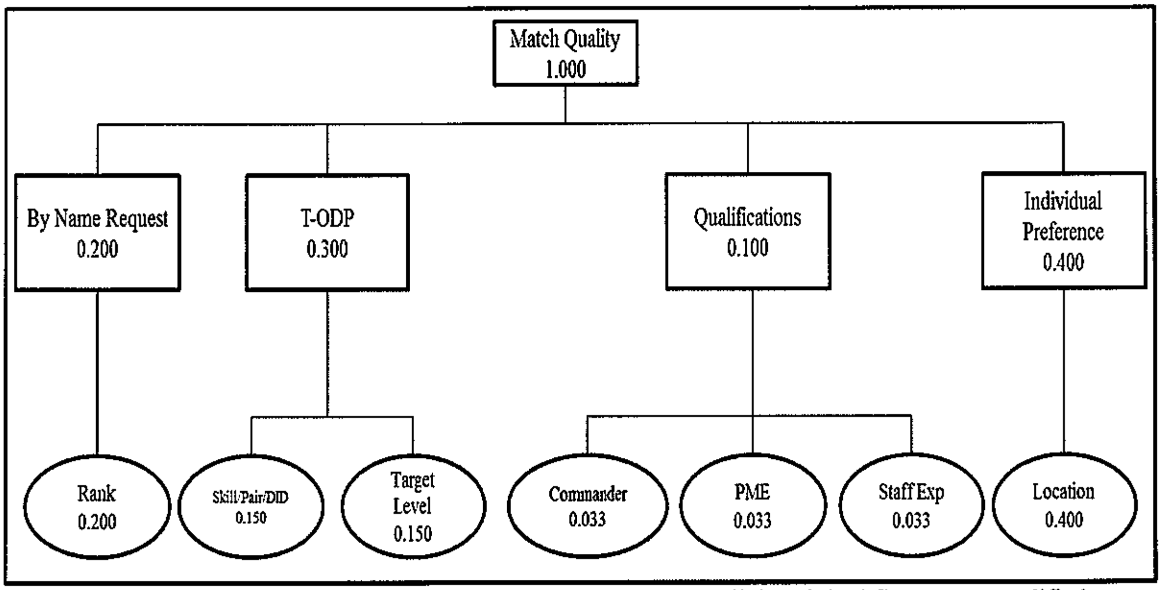
In their master's thesis, Adam Hooper and Greg Ostrin (2012) developed an IP model that optimizes the assignment of Marine Corps officers by minimizing costs. They included several factors as constraints such as billet vacancies, duty station preference, and the seniority of the individual Marine. Although cost is significant factor in allocating resources especially during times of economic budget constraints, the assignment of individuals should also include quality as a weighting factor.

2. Optimizing Marine Security Guard Assignments

Marco Enoka (2011) focused on optimizing MSG assignments using a multi-commodity network flow model. In his model, he used MSG experience as the commodity. He developed a Marine Security Guard Assignment Tool (MSGAT) that uses a Balance Model Formulation (BALMOD) with the goal of matching Marines to billets based on a specified number of attributes. His model was very detailed oriented and focused on quality of assignments while meeting several attribute constraints. His model assigned MSGs to specific detachments by incorporating individual preferences for assignment among several other attributes. Finally, in his model, Enoka (2011) developed a means in MSGAT to automate the required communication between MCESG HQ and each region, thereby increasing efficiency with the assignment process. However, the MSGAT is no longer being used by MCESG assignment personnel. Possible reasons for this include the level of operator understanding of the model and turnover with assignment personnel. The model developed in this paper is different than the model Enoka proposed, in that it can be modularized to fit a sample size of the population or the entire group of movers. Additionally, the model proposed in this paper provides a baseline of assignments to a decision-maker by spreading MSGs across the region level. The MCESG assignment section can then use this information to further assign Marines to the detachment level.

3. Value-Focused Thinking

Ralph Keeney (1992) provided an alternative view on decision-making from the traditional approach of choosing among a list of alternatives. He explained that "values are more fundamental to a decision problem than are alternatives" (Keeney, 1992, p. 3) and "they are also more fundamental than the methodology for linking a final objective to the decision process" (Keeney, 1992, p. 3). His process included quantifying the fundamental objectives by weighting attributes for a decision situation. Adding these attributes is fundamental in "understanding that the quantification of an objective is a powerful tool to aid in qualitatively identifying and clarifying objectives in a specific decision context ... and is an important part of value-focused thinking" (Keeney, 1992, p. 64). In his thesis research, Wylie (2007) applied Keeney's value-focused thinking approach to optimize rated officer staff assignments. He developed a model to "quantify how well an alternative, in this case a match, meets the overall objective, to maximize value" (Wylie, 2007, p. 3) of assigned officers. He followed two steps in developing an objective value function that was used to evaluate the different list of alternatives. Working with the Headquarters Air Force (HAF) Operations Assignments Branch (OSAB), Wylie developed criteria to quantify experience, performance, and other qualifications deemed important in the assignment process. These categories are depicted in Figure 2 and are listed as follows: By Name Request, T-ODP (Transitional Officer Development Plan), Qualifications, and Individual Preference. Each category is given a respective weight (e.g., By Name Request has a weight of 0.2.)



Note. This figure is based on a figure in Wylie (2007, p. 21). Wylie's original figure was modified to include the values for each attribute.

Figure 2. Officer Requirements Value Hierarchy

Wylie then developed additional evaluation criteria for each category. Table 2 is an example of the measurement scale associated with the evaluation criterion Rank of Requesting Official, under By Name Request.

Table 2. Measurement Scale for Rank

Rank of Requesting Official	Scale
General	1
Lieutenant General	0.8
Major General	0.6
Brigadier General	0.4
Colonel	0.2
Lieutenant Colonel	0.1
No BNR	0

The scale in Table 2 is based on the rank of the officer submitting the By Name Request on behalf of the officer being assigned. Each of the other three categories has an associated measurement scale similar to the Rank measurement scale and is used to quantify the overall value hierarchy for assigning air force officers to billet assignments.

III. DATA, MODEL DEVELOPMENT, AND METHODOLOGY

A. INTRODUCTION

Data collection, model development, and methodology and are reviewed in this chapter.

B. DATA COLLECTION

The data for this thesis were obtained from MCESG senior leaders and assignment personnel located at Marine Corps Base Quantico. The data cover the entire population of Marines who were slated as movers for the graduation class movement cycle 1-13. This was the first class graduating in Fiscal Year 2013. Individuals are given identifiers referenced by rank and tenure on the program and are used for the purpose of creating a programming model. No personal or private information was obtained or used in this research.

1. Model Description—Assignment IP

Utilizing mathematical programming methods, a model was developed to equitably distribute the quality of MSG assignments across nine MCESG regions. The definition of Quality (Q) is flexible in that it is based on a decision-makers preference and can be a function of multiple categories or a single one. In this model, Q is defined as a function of the categories Recommendation, Rank, Experience and MSG Rating, which are explained in Section C of this chapter. The objective of the model is to ensure that quality is spread evenly across each of the nine regions by minimizing the sum of squared differences for all regions. This model is a nonlinear integer programming assignment model. The model uses a value-based hierarchy measurement scale that places weights on specific attributes for individuals to quantify the quality of each Marine. Although specifically developed for the assignment of watch standers to the region level, the model can also be used for the assignment of watch standers within a region to the detachment level, and can even be applied to the assignment of detachment commanders.

C. MODEL DEVELOPMENT AND METHODOLOGY

1. Variables

The following variables are used in model development.

i = Individual Marine

j = Assigned region after optimization run

k = Current region before optimization run

n = Number of Marine Security Guards

v = Soft constraint value for Recommendation

w = Soft constraint value for Rank

x = Soft constraint value for Experience

y = Soft constraint value for MSG Rating

Q = Quality

The following weighting factor coefficients are used in model development.

α = Regional commanding officer/first sergeant recommendation (0,1,2)

β = Rank (0,1,2)

γ = Experience (0,1,2)

θ = MSG Rating (0,1,2)

Z = Objective function to be minimized

The following decision variables are used in model development.

$$X_{kij} = \begin{cases} 1 \text{ if MSG } i \text{ is assigned to job } j \\ 0 \quad \text{otherwise} \end{cases}$$

X_{kij} = MSG is assigned to region j

2. Notation Form

$$Q_i = f(\text{Recommendation, Rank, Experience, and MSG Rating}) \tag{1}$$

$$IQ_i = (\alpha \times \text{Recommendation}) + (\beta \times \text{Rank}) + (\gamma \times \text{Experience}) + (\theta \times \text{MSG Rating}) \tag{2}$$

$$AQ_j = \sum\nolimits_{i \in \mathrm{Reg}_j}^{n} \frac{IQ_i}{n_j} \tag{3}$$

As shown in Equation 1, Q is a function of the categories Recommendation, Rank, Experience, and MSG Rating. The Individual Quality (IQ) for an MSG follows Equation 2, where IQ for an individual is equal to the sum product of each weighted category and its respective value. In Equation 3, the Average Quality (AQ) for region j is the summation of the total IQ for all individuals assigned to region j divided by the total number of MSGs n assigned to region j.

3. Objective Function

$$\text{Minimize } Z = \sum_{j<l} (AQ_j - AQ_l)^2 \qquad \text{where } j = 1,2,\ldots 9 \tag{4}$$

Equation 4 is a nonlinear objective function that minimizes the sum of squared differences of AQ among all nine regions.

4. Constraints

$$\sum_{i=1}^{9} x_{kij} = 1, \ \forall i \tag{5}$$

$$\sum_{i=1}^{n} X_{kij} \le n_j, \forall j \tag{6}$$

$$X_{kij} = 1 \text{ or } 0 \ (i = 1,2,\ldots,n) \tag{7}$$

$$X_{kij} = 0, \ \text{if } k = j \tag{8}$$

$$X_{kij} \ge 0, \ \text{for all } k, i, \text{and } j \tag{9}$$

In Equation 5, constraint limits the assignment of each MSG to only one of the nine regions. In Equation 6, constraint ensures that the supply of MSGs meets the required demand at each region. In Equation 7, constraint is a binary constraint that ensures an MSG is assigned to only one region. In Equation 8, constraint does not allow an MSG to be assigned to the same region consecutively. In Equation 9, constraint ensures non-negativity for both MSGs and regions.

5. Model Development

The assignment model uses a mathematical equation that applies weighting factors as attributes for individuals based on four categories. These categories are highlighted as the most important factors currently used by MCESG HQ decision-makers involved in the assignment process. The Q of individuals is a function of the following categories: Recommendation, Rank, Experience, and MSG Rating. Figure 3 is an overview of the categories and the evaluation criteria used to weight the IQ of each Marine.

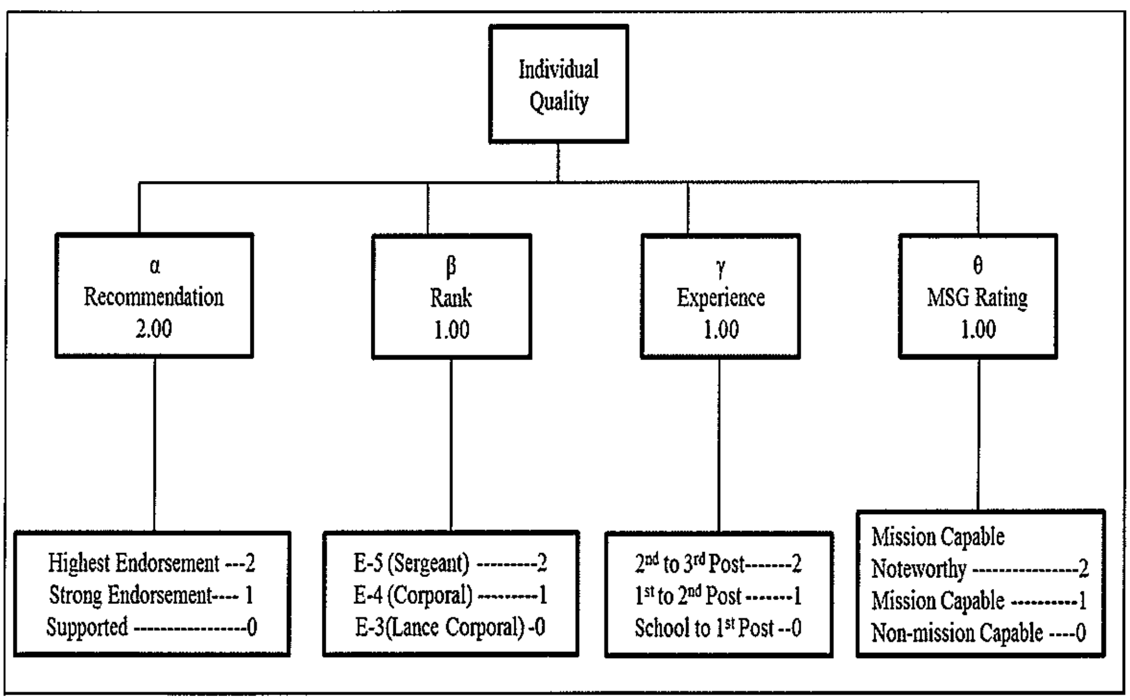


Figure 3. Individual Quality Weighted Factors

Each category has a coefficient for the *IQ* equation and is given a weighting factor of 1, with the exception of Recommendation, which is weighted with a factor of 2. These factors are given values according to a decision-maker's preference with respect to each attribute (i.e., $\alpha = 2$ and $\beta = \gamma = \theta = 1$). This equates to the Recommendation attribute having a greater value than the attributes for Rank, Experience, and MSG Rating. This also translates into Recommendation having twice as much value as Rank, Experience, and MSG Rating. Additionally, these coefficients can be turned on or off based on the preference of the decision-maker or these coefficients can be modified to take different values. For example, if during a specific assignment cycle, a decision-maker only wanted to quantify an individual's Recommendation and Experience, the respective coefficients for Rank and MSG Rating would be given values of 0. Figure 4 is an example of *IQ* for a Marine with Recommendation and Experience turned on and Rank and MSG Rating turned off. Each of the four categories has an associated weighted scale for the evaluation criteria.

Individual Quality = (α * value scale) + (β * value scale) + (γ * value scale) + (θ * value scale); where $\alpha = \gamma = 1$ & $\beta = \theta = 0$

OR

= (1 * value scale) + (0 value scale) + (1 * value scale) + (0 * value scale)

Figure 4. Individual Quality Weighting Recommendation and Experience

Working closely with MCESG HQ assignment personnel, a value scale for each of the quality categories was created. Figure 5 shows the respective values for each category in the *IQ* equation.

Recommendation Value Scale	Value
Highest Endorsement	2
Strong Endorsement	1
Supported	0

Rank Value Scale	Value
(E-5) Sergeant	2
(E-4) Corporal	1
(E-3) Lance Corporal	0

Experience Value Scale	Value
2nd to 3rd Post	2
1st to 2nd Post	1
School to 1st Post	0

MSG Rating Value Scale	Value
Noteworthy	2
Mission Capable	1
Non-Mission Capable	0

Figure 5. Value Scale for Coefficients

The Recommendation evaluation criterion has three possible weighting factors and is considered the most important evaluation category, according to MCESG assignment personnel. These factors are assigned by a Marine's current regional commanding officer and first sergeant. For the average watch stander, the regional commander and first sergeant are in the best position to provide this assessment, based on a year's worth of observation time during command visits, input from the Marine's detachment commander, and evaluations from the Marine's respective inspecting officer's (IO) semi-annual inspection (SAI). The greatest weight a Marine can receive for this attribute is a value of 2. This value translates into an exceptional Marine who performs above average with respect to other Marines in the region. The lowest weight a Marine can receive for this attribute is a value of 0. This value translates into an average Marine who accomplishes assigned tasks on a daily basis and performs within expectations. It is up to the regional commander and first sergeant to determine the specific elements that should be included in the Recommendation evaluation criteria. The MSG School director and chief instructor (senior enlisted advisor) are in the best position to assign weights for Marines who are new to the program and have just completed initial training.

The Rank evaluation criterion has three possible weighting factors. These factors are assigned based on a Marine's E pay grade. The greatest weight a Marine can receive for this attribute is a value of 2. This value translates into an E-5, or rank of sergeant. The lowest weight a Marine can receive for this attribute is a value of 0 for an E-3, or rank of lance corporal. The Rank evaluation criterion places a greater value on a Marine sergeant due to the experience, time in service, expected maturity level, and judgment that is associated with his rank.

The Experience evaluation criterion has three possible weighting factors. These factors are assigned according to the tenure of a Marine on the MSG program. The successful completion of a one-year equivalent assignment is considered one post. The greatest weight a Marine can receive for this attribute is a value of 2. This value translates into an MSG who has successfully completed two one-year equivalent assignments and will be transferring to a third posting. Marines who have recently completed initial training at the MSG School receive a value of 0.

The MSG Rating evaluation criterion has three possible weighting factors. For Marines currently assigned to an MSG detachment, the factors are assigned based on a Marine's performance during an SAI conducted by his respective IO. The highest grade a Marine can receive during an SAI is a grade of mission capable noteworthy. This translates into a value of 2. The lowest grade a Marine can receive is a non-mission capable (NMC) and translates into a value of 0. Similarly, for Marines undergoing training at the MSG school, the factors are assigned based on a Marine's overall performance, which is evaluated by the MSG School Director.

In the current *IQ* equation form, an individual Marine can be assigned a maximum score of 10 by turning on all of the current categories in the *IQ* equation, where Recommendation is valued at 2, and Rank, Experience, and MSG Rating are each valued at 1. This translates into a sergeant who receives the highest endorsement from his regional commanding officer and first sergeant. This Marine will be assigned to a third post and is given the highest grade of mission capable noteworthy by his IO. Similarly, the lowest score an individual Marine can receive is a score of 0. This translates into a lance corporal completing initial formal MSG training at Quantico and who will be assigned to his first post. He is supported by his instructors at MSG School and receives a MSG Rating of NMC from the MSG School Director.

6. Model Methodology

The first step after model development was to obtain an approximate number of MSGs reassigned during any movement cycle and an approximate number of Marines who complete MSG School every cycle. Only the number of Marines remaining on the program was used. The number of Marines who were leaving the program after their third post was not used because this was irrelevant. The list obtained from MCESG included individual ranks and experience level for Marines. Each Marine was then given an identifier based on his rank and experience on the program. Finally, Marines were assigned respective values for each category. Because only names were used as line–item placeholders with associated ranks and experience level, values were randomly assigned for Recommendation and MSG Rating based on Microsoft Excel's random function generator. Marines listed as graduating from MSG School were each given a value of 0 for Experience, indicating that they would be assigned to their first post. MSGs currently assigned to a region were given an Experience value of either 1 or 2. These values identified the MSGs as moving on to a second or third posting. Finally, a list of billet demands at each region was provided by MCESG HQ based on a recent movement cycle. The total billet requirement at each region was held constant for each model.

Due to the 200 variables and constraints limitation of Microsoft Excel's basic Solver function, a Premium Solver Platform and upgraded software engine was used. This software is from Frontline Systems Inc., is compatible with Microsoft Excel, and has the ability to handle up to 2,000 decision variables. Appendix A and B show how the decision variables and constraints are setup using the premium software. The total population of movers is 223 Marines, which includes 144 MSGs already assigned to a region and the remaining 79 Marines expected to graduate from MSG School. These decision variables alone total over 2,000. Approximately an additional 4,000 constraint variables are added to this number which easily exceeds Microsoft Excel's basic Solver variable threshold. As a result, the 223 Marines were divided into thirds and were used to run the assignment model three times. These groupings were held constant for each of the four IP models.

Four nonlinear programming models were developed to distribute the quality of Marines evenly throughout the nine regions. Each model calculated beginning AQ, IQ and final AQ for each region against a set of constraints and billet demand requirements. Each model equitably distributed the quality of MSGs for the total population of movers to the nine possible regions by minimizing the AQ differences throughout each of the regions. The objective function minimized the AQ by taking the sum of squared differences of quality among all regions. Each model has its strengths and weaknesses that are discussed later in this chapter. The results of the models are not intended to be compared against each other, however, there are several calculations used that are common for each model. These common calculations are discussed in the following sections.

a. *Calculating Beginning Average Quality by Region*

To reduce any potential bias in the model, the entire population was randomly divided into thirds. Next, the approximate beginning *AQ* for each region and *AQ* for Marines at school was determined. This provided a baseline to compare final *AQ* values for regions after distributing quality. Also, a weighted average was calculated using the current *IQ* of the total number of Marines at each region. Because the data obtained from MCESG did not include a list of all MSGs on the program who were not moving, this made it difficult to calculate beginning *AQ* for each region. Therefore, an ad hoc method was used to approximate this value. A separate weighted average was calculated using only the *AQ* of Marines at MSG School. This number was multiplied by the difference of Marines currently assigned to a region and the required number of MSGs at that region. This value was added to the current weighted *AQ* for each region and then divided by the total number of MSGs required at each region. Equation 10 is an example of the ad hoc weighted *AQ* calculation.

$$\frac{(n \text{ @ region} j \times AQ_j) + (n \text{ required @ region } j \times AQ \text{ at School})}{(n \text{ @ region} j + n \text{ required @ region} j)} \qquad (10)$$

b. *Baseline Objective Function Z for Each Model*

The beginning *AQ* value for each region was used to provide a baseline objective function value of *Z* for each model. The objective function equation for *Z* was used to minimize the sum of squared differences of *AQ* before assignments. This value is compared to ending *Z* values and indicates how well the model does in minimizing the quality of assignments throughout each of the regions. The objective function *Z* equation is described in Section 4 of this chapter.

c. *Transferring Average Quality to Subsequent Assignments*

Because the population of movers exceeded the number of variables and constraints that Microsoft Excel Solver could manage, a methodology was developed to transfer the *AQ* of assignments to subsequent optimization runs. This value was calculated by taking the *AQ* for each region and multiplying it by the total number of

Marines assigned to that region from the previous optimization runs. Equation 11 illustrates the formula used to transfer AQ to subsequent assignments.

$$(n \text{ assigned to region}_j \text{ from previous optimization run} \times AQ_j \text{ from previous optimization run}) \qquad (11)$$

This value was factored into each subsequent optimization runs by enabling the model to incorporate previous assignments with future assignments. If the AQ of individuals remaining at a current region who are not moving is available, their AQ should not be calculated and transferred to subsequent assignments.

d. Calculating Ending Average Quality by Region

The IQ equation is used to calculate the final AQ quality for each region. The total IQ for each region is divided by the total number of MSGs assigned to that region (n_j) to calculate each region's ending AQ. The AQ from the first and second optimization runs is transferred to the third and final optimization run for each model. The AQ value for each region is used to distribute the quality of MSGs by minimizing the sum of squared differences of each region's final AQ value.

e. Soft Constraints

Soft constraints are used in each model to provide a decision-maker with the option of using security levels for each category. A security level is defined as a value that a decision-maker does not want to fall below for a specific category. Soft constraints can be applied for any category and are not associated with the coefficient values or used to calculate AQ for a region. The soft constraint variables for each category are v for Recommendation, w for Rank, x for Experience, and y for MSG Rating. For example, a soft constraint value for Rank could be 0.5, where $w = 0.5$. This translates into a decision maker wanting to have the AQ of Rank for each region to be above 0.5, or on average slightly more senior than that of an E-3, lance corporal.

f. Model 1—Distribution of All Categories

Model 1 uses all four categories in the IQ equation with respective values of 2, 1, 1, and 1 for Recommendation, Rank, Experience, and MSG Rating. All soft constraint values are given a value of 0. This model is used when a decision-maker wants to minimize the sum of squared differences of AQ across all regions as a function of all categories. He places a higher value on Recommendation compared to Rank, Experience, and MSG Rating. The decision-maker has no preference for any of the categories to be above a specified threshold.

g. Model 2—Distribution of Recommendations

Model 2 uses only Recommendation as the criteria to spread AQ across each of the regions. This model values Recommendation at a value of 2 and all other coefficient categories with a value of 0. All soft constraint security levels are given a value of 0. This model is used when a decision-maker only wants to spread the recommendations assigned by the regional commanders, first sergeants, and MSG School Director. The decision-maker has no preference for any of the categories to be above a specified threshold.

h. Model 3—Distribution of Recommendations with Minimum Security Level Requirements for w, x, and y

Model 3 is similar to Model 2 in that only Recommendation is used as the criteria to spread AQ across each of the regions. The difference between the two models is that Model 3 uses a security level value for Rank, Experience, and MSG Rating. The security level values for the soft constraints are 0.1, where $w = x = y = 0.1$ for Rank, Experience, and MSG Rating respectively and $v = 0$. Recommendation is given a soft constraint value of 0 because in this model, Recommendation is the only category being used to spread quality.

i. Model 4—Distribution of All Categories with Minimum Security Level Requirements for v, w, x, and y

Model 4 is similar to Model 1 in that they both have the same values for each category, 2, 1, 1, and 1 for Recommendation, Rank, Experience, and MSG Rating respectively. The difference between the two models is that Model 4 uses security level soft constraint values for each category. These values are 0.05 for v, w, x, and y, where $v = w = x = y = 0.05$. This is the most restrictive of all the models since it places a value on all four categories as well as sets a minimum threshold value for each attribute.

7. Limitations

The four models are limited due to the subjectivity involved in quantifying the value of each category and weighted attribute. To best quantify the *IQ* of a Marine, cardinal numbers should be used in the value hierarchy scale as both coefficients and weighted attributes. However, each model uses the preferences of decision-makers at MCESG based on ordinal numbers. Ordinal numbers were used because of the difficulty in using an accurate value to place on categories such as Recommendation. For example, in reality, if a decision-maker gives an individual a Recommendation value of 4 and a Rank value of 2, a statement can only be made that the decision-maker places a higher value on the recommendation from a regional commander and first sergeant than on the rank of the individual. We cannot make the conclusion that the recommendation from the regional commander and first sergeant should be given twice as much value as rank. However, regardless of the type of mathematical programming software used, all values are treated as cardinal numbers. Therefore, in the previous example, recommendation is treated as having twice as much value as rank.

Another limitation with this research is with the data collected from MCESG. A snap-shot in time was taken with an accurate number of Marines at each MSG region based on rank and experience. However, these values do not accurately depict the newly assigned MSGs nor do they include recommendation values from the regional commanding officers, first sergeants, or MSG School Director. To account for this, MSGs at the regions and MSG School were given random values for their Recommendation and MSG Rating criteria. Also, the data from MCESG does not include the total number of Marines on the program who are not moving during the movement window. This required the ad hoc calculation to establish a beginning *AQ* baseline value.

A final limitation is in the platform used to run each model. The decision-makers at MCESG HQ currently use the spreadsheet functions of Microsoft Excel to track and manage MSGs during the assignment process. Because Marines in general have a good working knowledge of the basic functions of Microsoft Office programs, Microsoft Excel 2010 Solver was used as the platform to run this model. However, the standard

Microsoft Excel Solver add-in is limited to 200 decision variables for both linear and nonlinear problems and 1,000 constraints and 250 constraints for linear and nonlinear problems respectively. Because of this limitation, the Solver premium software was used and required the total population of movers to be separated into three groups. In order for MCESG assignment personnel to replicate the use of this model, they would be required to purchase the upgraded capability instead of using Excel's standard Solver functionality. Or, they could increase the number of groups to 10% samplings to ensure the variable and constraint limitations of excel aren't exceeded.

IV. RESULTS AND ANALYSIS

A. RESULTS

The results for each model are covered in this chapter. A section is devoted to each model and provides a summary of assignments, *AQ* broken down by region, a graphical depiction of overall assignments, and a statistical summary overview. Section A begins with the baseline results for beginning *AQ* for Models 1 and 4.

1. Beginning Average Quality for All Models

Figure 6 is a chart that depicts the beginning *AQ* for Models 1 and 4 with associated standard error (SE) bars. The beginning values are the same for both models because they are set up with exactly the same weights and values for each MSG. The methodology for calculating the values for each Marine is explained in Section 6 of Model Development. As the chart depicts, there is a significant variance and SE across all regions which are statistically different from each other (P>0.01). Region 9 has the highest *AQ* with a value of 6.00 and Region 1 has the lowest *AQ* with a value of 4.11. The average *AQ* for all nine regions is 4.93.

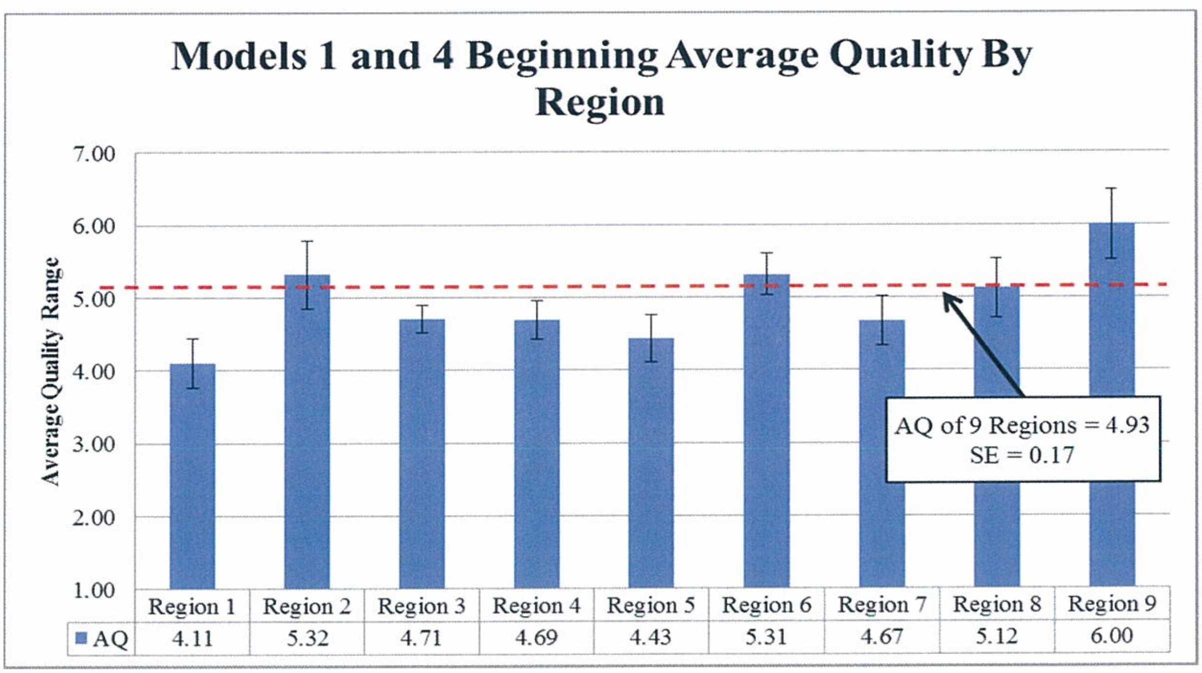


Figure 6. Models 1 and 4 Beginning *AQ* by Region

Figure 7 is a chart that depicts the beginning *AQ* for Models 2 and 3 with associated SE bars. The beginning values are the same for both models because they are set up with exactly the same weights and values for each MSG. The methodology for calculating the values for each Marine is also explained in Section 6 of Model Development. As the chart depicts, there is a significant variance and SE across all regions which are statistically different from each other (P>0.01). Region 6 has the highest AQ with a value of 2.43 and Region 5 has the lowest AQ with a value of 1.46. The average AQ for all nine regions is 1.95.

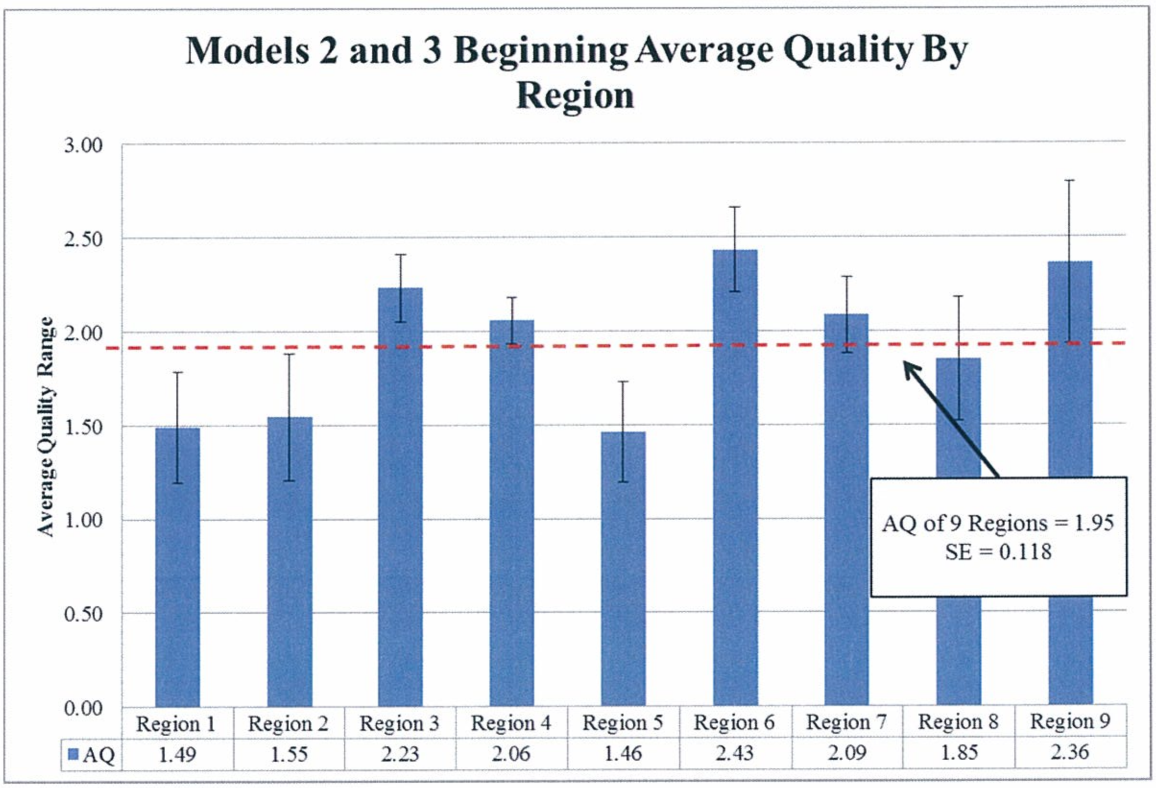


Figure 7. Models 2 and 3Beginning *AQ* by Region

2. Results of Model 1-- Distribution of All Categories

Table 3 is a sequence of the assignments by region for Model 1. A total of 223 Marines were assigned based on total requirements. The 223 Marines were grouped in a sequence of 75 first assignments, 75 second assignments, and 73 third assignments.

Table 3. Model 1 Sequence of Assignments

Model 1 Summary Assignments										
	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Region 7	Region 8	Region 9	Total
Total Requirements	20	22	38	17	23	34	37	21	11	223
First Assignments	1	9	2	2	4	6	21	19	11	75
Remaining	19	13	36	15	19	28	16	2	0	148
Second Assignments	6	12	5	10	9	15	16	2	0	75
Remaining	13	1	31	5	10	13	0	0	0	73
Third Assignments	13	1	31	5	10	13	0	0	0	73
Total Remaining	0	0	0	0	0	0	0	0	0	

Table 4 is a summary of *AQ* by region after all iterations of optimization runs. The *AQ* beginning value before assignments is listed in the first column by region. The 1st Assignments column is the first iteration of 33% grouping. Similarly, the 2nd Assignments and 3rd Assignments columns are the second and third iteration of 33% grouping respectively. The last column under 3rd Assignments lists the final *AQ* by region. The objective function value Z is listed under Beginning Quality and by each of the three assignment optimization runs. The final objective function value *Z* is listed under 3rd Assignments which is the sum of squared errors for all iterations of assignments.

Table 4. Model 1 Summary of *AQ* by Region

Model 1 Average Quality By Region				
	Calculated Ad Hoc Beginning Quality	1st Assignments	2nd Assignments	3rd Assignments
Region 1	4.11	5.00	4.86	4.85
Region 2	5.32	4.67	4.90	4.82
Region 3	4.71	5.00	5.00	4.97
Region 4	4.69	4.50	4.75	4.82
Region 5	4.43	4.25	4.92	5.00
Region 6	5.31	4.83	4.95	4.94
Region 7	4.67	4.62	4.78	4.78
Region 8	5.12	4.84	4.86	4.86
Region 9	6.00	4.64	4.64	4.64
School	4.14			
Z Model 1 (Obj Func)	23.18	4.25	0.91	0.88

Figure 8 depicts the final *AQ* by region in a chart. The *AQ* for each region is shown by the bar height and associated SE bar.

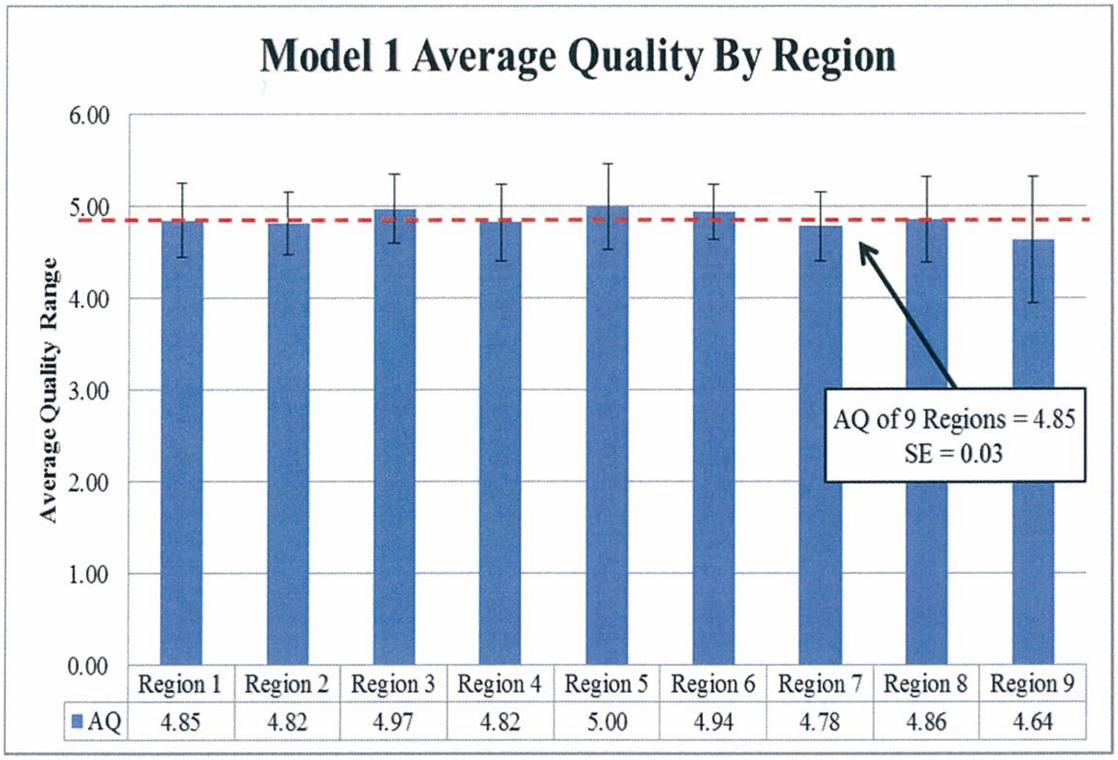


Figure 8. Model 1 *AQ* by Region

As Figure 8 depicts, the average quality across regions are very similar. *AQs* are all statistically no different from one another (p<0.01). 5.00 is the highest *AQ* value and 4.64 is the lowest *AQ* value. Model 1 distributes quality across the regions using all categories, Recommendation, Rank, Experience, and MSG Rating. The 0.5 value difference between the highest and lowest *AQ* value can equate in terms of the difference in rank between an E-3 lance corporal and E-4 corporal since the value scale for Rank is 0, 1, and 2 from lance corporal to sergeant respectively.

Table 5 is a statistical summary for Model 1 assignments. This table includes the total number of Marines assigned by region, *AQ* by region, standard deviation (SD) and SE by region. As previously discussed, the difference between the highest and lowest *AQ* value is 0.5. Between this range of values, all nine regions have an *AQ* of 4.854 with a

SD of only 0.111. Model 1 significantly improves quality distribution of MSGs through the sum of squared differences with a beginning Z value of 23.18 to a final value of 0.88.

Table 5. Model 1 Statistical Summary

Model 1 Statistical Summary of Assignments									
	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Region 7	Region 8	Region 9
Total MSGs Assigned	20	22	38	17	23	34	37	21	11
Average Quality By Region	4.85	4.82	4.97	4.82	5.00	4.94	4.78	4.86	4.64
Standard Deviation	1.81	1.59	2.31	1.74	2.22	1.70	2.29	2.10	2.29
Standard Error	0.41	0.34	0.37	0.42	0.46	0.29	0.38	0.46	0.69

Average Quality of 9 Regions	4.854	Average Quality of all movers	4.874
Standard Deviation of AQ of 9 Regions	0.111	Standard Deviation of all movers	2.010
Standard Error of 9 Regions	0.037	Standard Error of all movers	0.135

3. Results of Model 2-- Distribution of Recommendations

Table 6 is a sequence of the assignments by region for Model 2. A total of 223 Marines were assigned based on total requirements. The 223 Marines were grouped in a sequence of 75 first assignments, 75 second assignments, and 73 third assignments.

Table 6. Model 2 Sequence of Assignments

Model 2 Summary Assignments										
	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Region 7	Region 8	Region 9	Total
Total Requirements	20	22	38	17	23	34	37	21	11	223
First Assignments	3	3	5	6	5	7	14	21	11	75
Remaining	17	19	33	11	18	27	23	0	0	148
Second Assignments	3	2	3	4	17	23	23	0	0	75
Remaining	14	17	30	7	1	4	0	0	0	73
Third Assignments	14	17	30	7	1	4	0	0	0	73
Total Remaining	0	0	0	0	0	0	0	0	0	

Table 7 is a summary of AQ by region after all iterations of optimization runs. The AQ beginning value before assignments is listed in the first column by region. The 1st Assignments column is the first iteration of 33% grouping. Similarly, the 2nd Assignments and 3rd Assignments columns are the second and third iteration of 33% grouping respectively. The last column under 3rd Assignments lists the final AQ by region. The objective function value Z is listed under Beginning Quality and by each of the three assignment optimization runs. The final objective function value Z is listed under 3rd Assignments which is the sum of squared errors for all iterations of assignments.

Table 7. Model 2 Summary of *AQ* by Region

Model 2 Average Quality By Region				
	Calculated Ad Hoc Beginning Quality	1st Assignments	2nd Assignments	3rd Assignments
Region 1	1.49	2.00	2.00	1.90
Region 2	1.55	2.00	2.00	1.91
Region 3	2.23	2.00	2.00	2.00
Region 4	2.06	1.67	2.00	1.88
Region 5	1.46	1.60	2.00	1.91
Region 6	2.43	1.71	2.00	1.94
Region 7	2.09	1.57	2.16	2.16
Region 8	1.85	2.10	2.10	2.10
Region 9	2.36	1.82	1.82	1.82
School	2.23			
Z Model 2 (Obj Func)	10.23	2.85	0.61	0.86

Figure 9 depicts the *AQ* by region in a chart. The *AQ* for each region is shown by the bar height and associated SE bar.

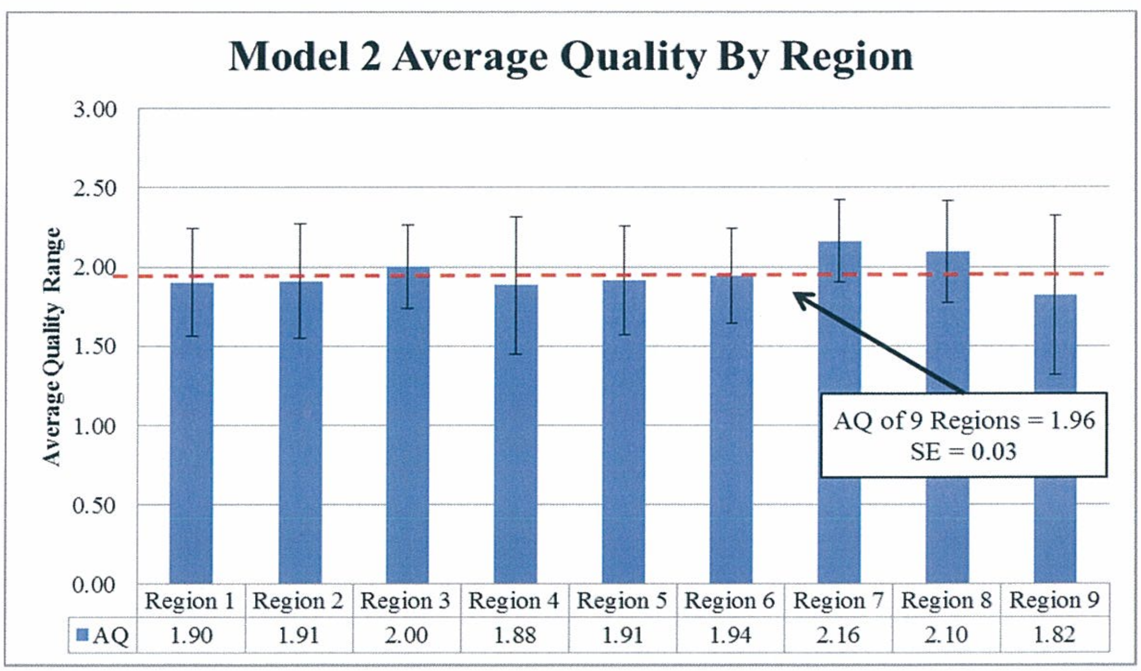


Figure 9. Model 2 *AQ* by Region

As Figure 9 depicts, the average quality across regions is very similar with Regions 7 and 8 having slightly higher *AQ* values of 2.16 and 2.10. In this model, the *AQs* are all statistically no different from one another ($p<0.01$). 2.16 is the highest *AQ* value and 1.88 is the lowest *AQ* value. Model 2 distributes quality across the regions using only the Recommendation category. In this model, the Recommendation weight has a value of 2. Therefore, the highest *IQ* value an MSG can be given is 4. The *AQ* of the nine regions is 1.96. This value can be interpreted as the distributed quality of Recommendation across the nine regions is slightly below the Strong Endorsement value scale.

Table 8 is a statistical summary for Model 2 assignments. This table includes the total number of Marines assigned by region, *AQ* by region, SD and SE by region. As previously discussed, the difference between the highest and lowest *AQ* value is 0.28. Between this range of values, all nine regions have an *AQ* of 1.96 with a SD of only 0.109. Model 2 significantly improves quality distribution of Recommendation through the sum of squared differences with a beginning *Z* value of 10.23 to a final value of 0.86.

Table 8. Model 2 Statistical Summary

Model 2 Statistical Summary of Assignments									
	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Region 7	Region 8	Region 9
Total MSGs Assigned	20	22	38	17	23	34	37	21	11
Average Quality By Region	1.90	1.91	2.00	1.88	1.91	1.94	2.16	2.10	1.82
Standard Deviation	1.52	1.69	1.61	1.80	1.65	1.74	1.59	1.48	1.66
Standard Error	0.34	0.36	0.26	0.44	0.34	0.30	0.26	0.32	0.50

Average Quality of 9 Regions	1.958	Average Quality of all movers	1.982
Standard Deviation of AQ of 9 Regions	0.109	Standard Deviation of all movers	1.611
Standard Error of 9 Regions	0.036	Standard Error of all movers	0.108

4. Results of Model 3--Distribution of Recommendations with Minimum Security Level Requirements for w, x, and y

Table 9 is a sequence of the assignments by region for Model 2. A total of 223 Marines were assigned based on total requirements. The 223 Marines were grouped in a sequence of 75 first assignments, 75 second assignments, and 73 third assignments.

Table 9. Model 3 Sequence of Assignments

Model 3 Summary Assignments										
	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Region 7	Region 8	Region 9	Total
Total Requirements	20	22	38	17	23	34	37	21	11	223
First Assignments	2	2	4	2	4	9	21	20	11	75
Remaining	18	20	34	15	19	25	16	1	0	148
Second Assignments	8	6	3	5	13	23	16	1	0	75
Remaining	10	14	31	10	6	2	0	0	0	73
Third Assignments	10	14	31	10	6	2	0	0	0	73
Total Remaining	0	0	0	0	0	0	0	0	0	

Table 10 is a summary of *AQ* by region after all iterations of optimization runs. The *AQ* beginning value before assignments is listed in the first column by region. The 1st Assignments column is the first iteration of 33% grouping. Similarly, the 2nd Assignments and 3rd Assignments columns are the second and third iteration of 33% grouping respectively. The last column under 3rd Assignments lists the final *AQ* by region. The objective function value *Z* is listed under Beginning Quality and by each of the three assignment optimization runs. The final objective function value *Z* is listed under 3rd Assignments which is the sum of squared errors for all iterations of assignments.

Table 10. Model 3 Summary of *AQ* by Region

Model 3 Average Quality By Region				
	Calculated Ad Hoc Beginning Quality	1st Assignments	2nd Assignments	3rd Assignments
Region 1	1.49	2.00	2.00	1.90
Region 2	1.55	2.00	2.00	2.00
Region 3	2.23	2.00	2.00	1.95
Region 4	2.06	2.00	2.00	2.00
Region 5	1.46	2.00	2.12	2.00
Region 6	2.43	2.00	2.13	2.00
Region 7	2.09	1.90	2.27	2.27
Region 8	1.85	1.70	1.71	1.71
Region 9	2.36	1.64	1.64	1.64
School	2.23			
Z Model 3 (Obj Func)	10.23	1.51	2.83	2.41

Figure 10 depicts the AQ by region in a chart. The AQ for each region is shown by the bar height and associated SE bar.

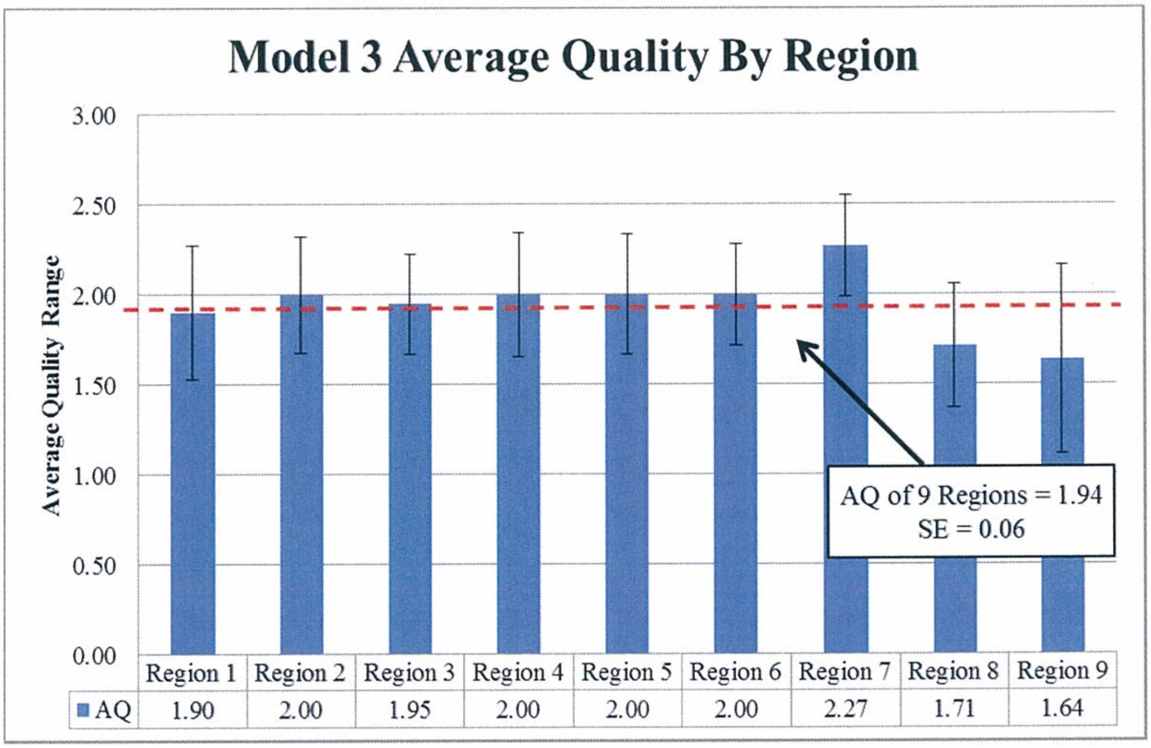


Figure 10. Model 3 AQ by Region

As Figure 10 depicts, the AQ across regions is very similar with the exception of Region 7 with the highest AQ of 2.27 and Regions 8 and 9 falling below the AQ for all regions of 1.94. In this model, the average qualities are all statistically no different from one another ($p<0.01$). 2.27 is the highest average quality value and 1.64 is the lowest AQ value at Region 9. This model is similar to the previous model in that it distributes quality across the regions using only the Recommendation category. However in this model, soft constraint values are used for security levels. Model 3 not only meets these security level requirements, it has a final AQ value very close to Model 2's AQ of 1.94 with a final AQ of 1.94.

Table 11 is a statistical summary for Model 3 assignments. This table includes the total number of Marines assigned by region, AQ by region, SD and SE by region. Model 3 has the largest difference between the highest and lowest AQ value is 0.63.

Between this range of values, all nine regions have an AQ of 1.94 with a SD of 0.183. This is the highest SD of the first three models. Unlike Model 2's improvement in quality distribution of 0.88, this model is only able to spread quality with a final Z value of 2.41.

Table 11. Model 3 Statistical Summary

Model 3 Statistical Summary of Assignments									
	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Region 7	Region 8	Region 9
Total MSGs Assigned	20	22	38	17	23	34	37	21	11
Average Quality By Region	1.90	2.00	1.95	2.00	2.00	2.00	2.27	1.71	1.64
Standard Deviation	1.65	1.51	1.71	1.41	1.60	1.63	1.71	1.59	1.75
Standard Error	0.37	0.32	0.28	0.34	0.33	0.28	0.28	0.35	0.53

Average Quality of 9 Regions	1.941	Average Quality of all movers	1.982
Standard Deviation of AQ of 9 Regions	0.183	Standard Deviation of all movers	1.611
Standard Error of 9 Regions	0.061	Standard Error of all movers	0.108

5. Results of Model 4--Distribution of All Categories with Minimum Security Level Requirements for v, w, x, and y

Table 12 is a sequence of the assignments by region for Model 4. A total of 223 Marines were assigned based on total requirements. The 223 Marines were grouped in a sequence of 75 first assignments, 75 second assignments, and 73 third assignments.

Table 12. Model 4 Sequence of Assignments

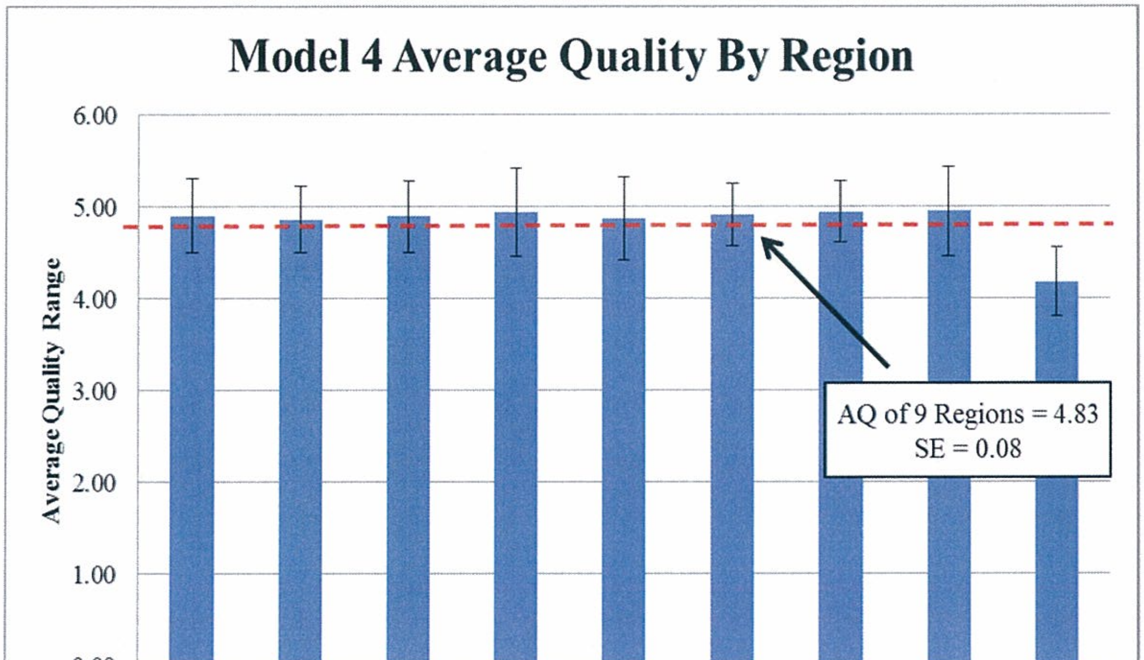
Model 4 Summary Assignments										
	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Region 7	Region 8	Region 9	Total
Total Requirements	20	22	38	17	23	34	37	21	11	223
First Assignments	4	4	2	5	6	8	14	21	11	75
Remaining	16	18	36	12	17	26	23	0	0	148
Second Assignments	4	5	3	12	8	20	23	0	0	75
Remaining	12	13	33	0	9	6	0	0	0	73
Third Assignments	12	13	33	0	9	6	0	0	0	73
Total Remaining	0	0	0	0	0	0	0	0	0	

Table 13 is a summary of AQ by region after all iterations of optimization runs. The AQ beginning value before assignments is listed in the first column by region. The 1st Assignments column is the first iteration of 33% grouping. Similarly, the 2nd Assignments and 3rd Assignments columns are the second and third iteration of 33% grouping respectively. The last column under 3rd Assignments lists the final AQ by region. The objective function value Z is listed under Beginning Quality and by each of the three assignment optimization runs. The final objective function value Z is listed under 3rd Assignments which is the sum of squared errors for all iterations of assignments.

Table 13. Model 4 Summary of AQ by Region

Model 4 Average Quality By Region				
	Calculated Ad Hoc Beginning Quality	1st Assignments	2nd Assignments	3rd Assignments
Region 1	4.11	5.25	4.88	4.90
Region 2	5.32	5.00	4.89	4.86
Region 3	4.71	5.00	5.00	4.89
Region 4	4.69	4.40	4.94	4.94
Region 5	4.43	4.67	4.71	4.87
Region 6	5.31	4.63	4.86	4.91
Region 7	4.67	4.57	4.95	4.95
Region 8	5.12	4.95	4.95	4.95
Region 9	6.00	4.18	4.18	4.18
School	4.14			
Z Model 4 (Obj Func)	23.18	8.23	4.57	4.31

Figure 11 depicts the *AQ* by region in a chart. The *AQ* for each region is shown by the bar height and associated SE bar.



	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Region 7	Region 8	Region 9
AQ	4.90	4.86	4.89	4.94	4.87	4.91	4.95	4.95	4.18

Figure 11. Model 4 *AQ* by Region

As Figure 11 depicts, the *AQ* across regions is very similar with the exception of Region 9 with the lowest *AQ* of 4.18. In this model, the average qualities are all statistically no different from one another ($p<0.01$). 4.95 is the highest *AQ* value and 4.18 is the lowest *AQ* value at Region 9. This model is similar to Model 1 in that it distributes quality across the regions using all categories. Soft constraint values are also used for security levels for every value making it the most restrictive of all models. With these threshold values, Model 4 is still able to distribute quality across all regions with a final *AQ* of 4.83. This value is only slightly less than Model 1's final *AQ* value of 4.85. One explanation for Model 4's slightly lower *AQ* could be a result of Region 9's final *AQ* value of 4.18. This value was assigned after the first iteration of assignments and assigned all 11 MSGs required for Region 9 with no room for improvement in subsequent optimization runs.

Table 14 is a statistical summary for Model 4 assignments. This table includes the total Marines assigned by region, *AQ* by region, and SD and SE by region. Of the four models, Model 4 has the largest difference between the highest and lowest *AQ* value which is 0.77. Between this range of values, all nine regions have an *AQ* of 4.83 with a SD of 0.245. This is the highest SD of four models. Unlike Model 1's improvement in quality distribution, this model is only able to spread quality with a final Z value of 4.31. Again, this could be the result of being the most restrictive of all four models.

Table 14. Model 4 Statistical Summary

Model 4 Statistical Summary of Assignments									
	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Region 7	Region 8	Region 9
Total MSGs Assigned	20	22	38	17	23	34	37	21	11
Average Quality By Region	4.90	4.86	4.89	4.94	4.87	4.91	4.95	4.95	4.18
Standard Deviation	1.80	1.67	2.39	1.98	2.16	2.01	2.01	2.22	1.25
Standard Error	0.40	0.36	0.39	0.48	0.45	0.34	0.33	0.49	0.38

Average Quality of 9 Regions	4.829	Average Quality of all movers	4.874
Standard Deviation of AQ of 9 Regions	0.245	Standard Deviation of all movers	2.010
Standard Error of 9 Regions	0.082	Standard Error of all movers	0.135

B. ANALYSIS

The purpose of this research is to develop an alternative method for MCESG senior leaders to better assign MSGs. The current process is overly taxing on assignment personnel due to the sheer number of Marines to be assigned. The coordination involved in the assignment process between MCESG HQ and regional commands can also be extremely challenging with the iterative nature of reviewing multiple draft assignments and maintaining proper version control of updated assignment lists. The current process will become even more difficult in the near future with the approved increase by Congress of 1,000 additional Marines to the MSG Program. The results previously discussed support the feasibility of implementing this model as a tool to complement MCESG's current assignment process.

1. Z Model Comparisons

Although the *Z* value of a model has no meaning in and of itself, the goal of the objective function for any of the four models is to get as close as possible to zero thereby minimizing the differences in *AQ*. The objective function for each model is to distribute the quality of Marines by minimizing the sum of square differences across the nine regions. A beginning Z value was calculated for each model before distributing quality of assignments to determine how well *AQ* was spread among the nine regions. A final Z value was then calculated for each model.

a. Independent Model Analysis

There are two ways to analyze Z values. First, the beginning and ending Z values for each model can be used to compare how well the model minimized the square differences of each region's *AQ*. For example, Model 1's beginning Z value for current MSGs assigned to each region using the ad hoc beginning quality equation is Z = 23.18. The ending Z value after the optimization run is Z = 0.88. Using the coefficient values of $\alpha = 2$ and $\beta = \gamma = \theta = 1$, Model 1 minimized the Z value by 96%. This can be interpreted as the beginning and ending *AQ* sum of square differences improving by 96%. *AQ* is defined in Model 1 as a function of Recommendation, Rank, Experience, and MSG Rating, where Recommendation is valued twice as much as each other category. Table 15 is a summary of the percent change for each model. The percent change for each model should be viewed independently of other models unless models are set up with exactly the same attributes and measuring criteria.

Table 15. Z Model Comparisons

Z Model Improvements				
	Model 1	Model 2	Model 3	Model 4
Beginning Z Value	23.18	10.23	10.23	23.18
Optimized Z Value	0.88	0.86	2.41	4.31
% Change	96.20%	91.59%	76.44%	81.41%

b. Z Value Comparisons across Different Models

The second way to analyze Z values is across models that use the same attributes and measuring criteria such as population, *IQ* equation, decision variables, and constraints. For example, Model 2 and 3 are set up exactly the same with the exception of different values for soft constraints. Therefore, Model 2 and Model 3's final Z values and percent improvements can be compared against each other. Model 2 does a better job of minimizing the sum of squared differences across each region with an ending Z = 0.86, which is also a 92% improvement from its beginning *AQ* sum of squared differences value. Similarly, Model 1 and Model 4's ending *Z* values and percent changes can be compared against each other, 96% compared to 81% respectively. This is expected because Model 3 and 4 have additional constraints that Models 1 and 2 do not have.

c. *Average Quality and Standard Deviation Comparisons*

Similar to *Z* value comparisons, the *AQ* and SD for each model can be compared in two ways, as a stand-alone model and in comparison to other models that use the same population, *IQ* equation, decision variables, and constraints. For example, Model 1 and Model 4's *AQ* and SD values can be compared to each other because they are set up the same. The beginning *AQ* for the total population of movers in Model 1 and 4 is 4.93. Table 16 is a summary of the beginning and ending values of *AQ* and SD for each model. Similarly, Model 2 and Model 3 have the same beginning SD of 0.355. The beginning *AQ* value alone provides no real meaning. However, when compared to ending *AQ*, SD, and *Z* values, a decision-maker is able to quantitatively measure how well quality is being spread throughout the MSG Program. Also, each respective SD provides a decision-maker with a reference of how much a region deviates from the entire populations *AQ*. For example, although Model 1 has a slightly lower final *AQ* of 4.85 compared to its beginning value of 4.930, Model 1's SD of 0.11 is significantly less than its beginning SD value of 0.535. This is expected since the objective function is to minimize the sum of squared differences of quality for each region resulting in SD value to be as small as possible. As shown in Table 16, each of the four models has ending SD values that are less than their respective beginning SD values.

Table 16. *AQ* and SD Comparisons

Average Quality and Standard Deviation Comparisons				
	Model 1	Model 2	Model 3	Model4
Beginning AQ	4.930	1.947	1.947	4.930
Ending AQ	4.854	1.958	1.941	4.829
Beginning SD	0.535	0.355	0.355	0.535
Ending SD	0.111	0.109	0.183	0.245

C. SUMMARY

The results of each model support the feasibility of implementing this IP model to help MCESG decision-makers quantify the quality of MSG assignments. *AQ* and *Z* values for each model alone provide no useful meaning to a decision-maker. However, using these values comparatively to beginning values of a region's disposition can provide a better quantitative measure for assessing current *AQ* distribution and future assignments. The purpose of this IP model is to complement the current assignment process instead of replacing it exclusively. The goal of the objective function for each model is the same, to minimize the sum of squared differences of *AQ* across all regions. There is inherent flexibility in the framework of the model to incorporate a decision-maker's ultimate goal. Chapter III describes how models can be set up with different options depending on the preference of a decision-maker. Categories can be used or turned off, they can be weighted differently, and soft constraint values can be set according to minimum desired threshold values. Additionally, the names of each category can be changed as well as the value for each category. For example, a decision-maker could replace the Recommendation category with Physical Fitness Test score and weight it accordingly. In summary, this IP model should be viewed as a resource tool to support decision-making, rather than an exclusive assignment tool.

V. CONCLUSION AND RECOMMENDATIONS

A. SUMMARY

As discussed in the previous chapter, the results of this IP model support its use to complement the current MCESG assignment process. The model showed up to a 96% improvement to the baseline beginning *AQ* with respective improvements for the other models as well. As the authorized increase to the MSG Program begins to materialize, the number of MSGs will increase correspondingly during each movement cycle. The increase in MSG manning requirements will significantly burden the current assignment process and will require more efficient methods to accomplish the assignment cycle.

The purpose of this research was to develop alternative methods to assist MCESG HQ decision-makers with more effectively assigning MSGs to fill DoS billet requirements. The IP model developed provides a decision-maker with the flexibility to define what aspects of *Q* of an MSG are most important in the assignment process and allows him to vary the value of each category accordingly. The results of the models provide a decision-maker with different options to focus on *Q*. The model is only constrained to the decision-makers creativity and the limitations of Microsoft Excel's Solver functionality. With some requisite training for MCESG assignment personnel, the assignment process can be implemented more efficiently with confidence supported by quantitative data that quality is being spread equitably across the entire program.

There are two options MCESG could pursue to implement this model. First, assignment personnel could use the basic Solver function that is provided with Microsoft Excel. Due to the decision variable and constraint limitations, the total population of movers would need to be reduced to 10% groupings, or no more than 20 individuals per optimization run. Although possible to implement in this manner, it becomes very tedious to manage, track, and transfer both assignments and *AQ* from optimization run to subsequent runs. The probability of error will increase as percent groupings decrease. In addition, using the IP model with the basic Solver function can take up to several hours for Microsoft to find a solution. This is a significant limitation to this implementation option.

The second and preferred method of implementing this model would require additional software upgrades to Microsoft Excel's basic Solver function, namely the Premium Solver Platform Software developed by Frontline Systems, and the requisite training. The cost of the upgrade at the current market price is approximately $3,000. This investment would manifest in the decrease in manual labor hours required to track and manage spreadsheets, and would facilitate a more efficient process with those involved. The difference in run time for the premium upgrade compared to the basic Solver is minutes instead of several hours for each optimization run. Frontline Systems markets software that is capable of incorporating upwards of 8,000 decision variables and constraints simultaneously. Using this type of software would eliminate the need to transfer AQ assignments from each optimization run and track billet demand requirements as they are filled. The ideal implementation scenario would be running only one IP model with the entire population of movers, thus reducing labor hours, facilitating coordination requirements with region HQs, and decreasing the probability of error with managing multiple spreadsheets and assignments.

1. Methods for MCESG Implementation

Assigning the right Marine to the right location to provide internal security at designated diplomatic facilities worldwide is critical to national security. This IP model provides a means to quantify MSGs based on how decision-makers define quality. As discussed in the Model Development and Methodology chapter, this model is designed to complement MCESG's assignment of MSG watch standers to the region level. In its current form, the model can be easily manipulated and applied to the assignment of watch standers from the region level to detachment level. For example, given a list of 30 Marines required to be assigned to Region 1 and the beginning AQ for 18 detachments in Region 1, the IP model can equitably distribute the quality of the 30 Marines across the 18 detachments by minimizing the sum of their squared differences. The IP model can also be applied to the assignment of detachment commanders and can also be used to assign inspecting officers to a region HQ. In sum, this model has multiple applications internal to the MSG Program with the requisite training and understanding of Microsoft Excel's Solver functionality. It provides the flexibility to a decision-maker to value and weight his preference in the assignment of individuals and quantitatively use those results as a baseline in the final assignment of individuals.

B. RECOMMENDATIONS FOR FURTHER RESEARCH

This IP model uses the sum of squared differences as its objective function equation. There are many other methods and techniques that could be used to optimize the assignment of MSGs, such as minimizing maximum quality by region, optimizing assignments by matching individuals to individual billet requirements as developed by Enoka (2011), or minimizing costs associated with PCS orders as developed by Hooper and Ostrin (2012). Although this IP model provides quantitative results to support a decision-maker in the assignment process, it does not take into account several other possible criteria that could be used. These criteria include an individual's preference of region or location, by name request of individuals by region commanders, or critical shortfalls in a region or at the detachment level. Last, this IP model provides results based on a set of established criteria. A different model could be developed with the same criteria using an alternative IP objective function such as maximizing quality of assignments. Research could then compare how well this model optimized the quality of MSG assignments to the new model.

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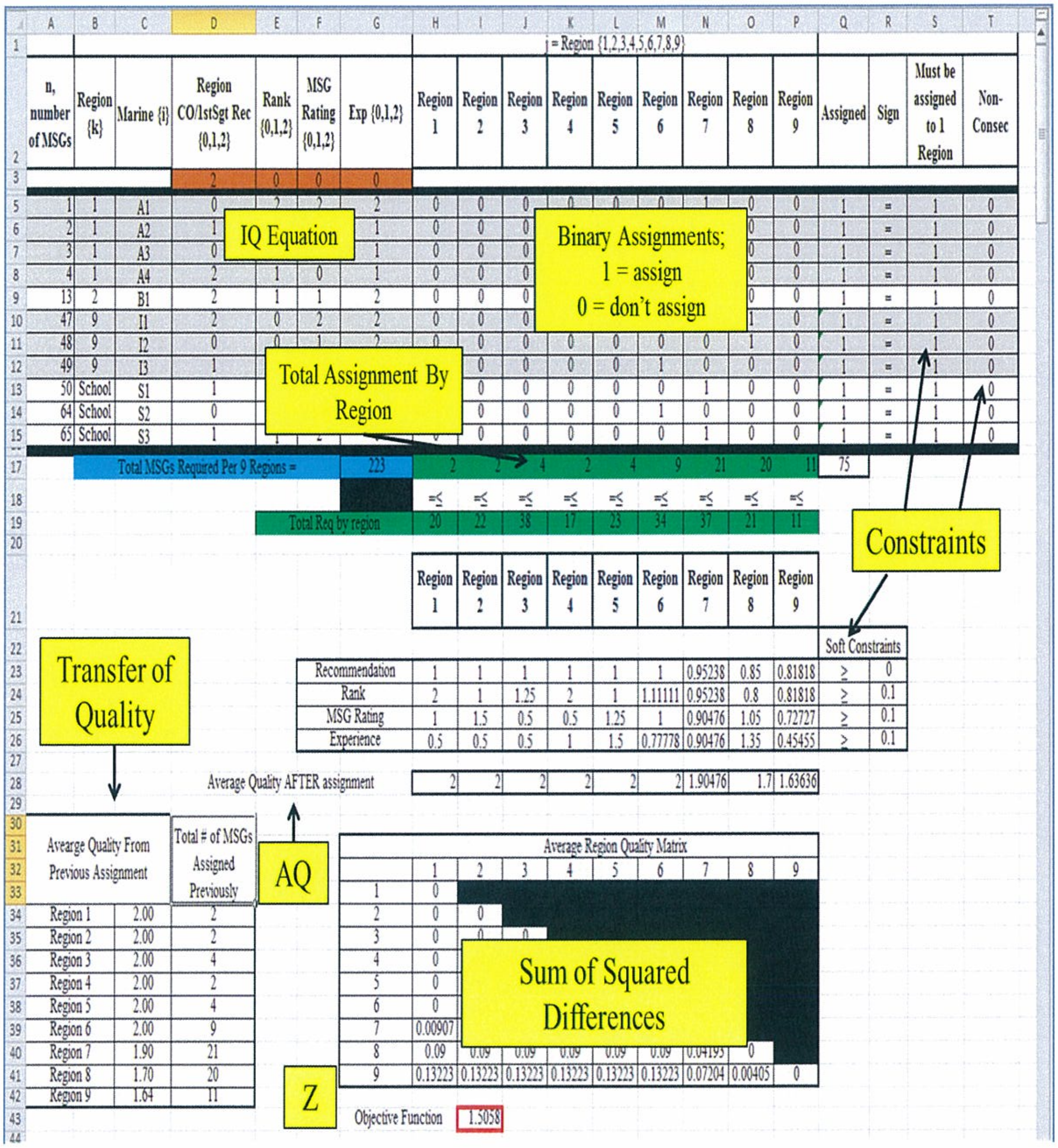
APPENDIX A: MODEL SETUP IN EXCEL



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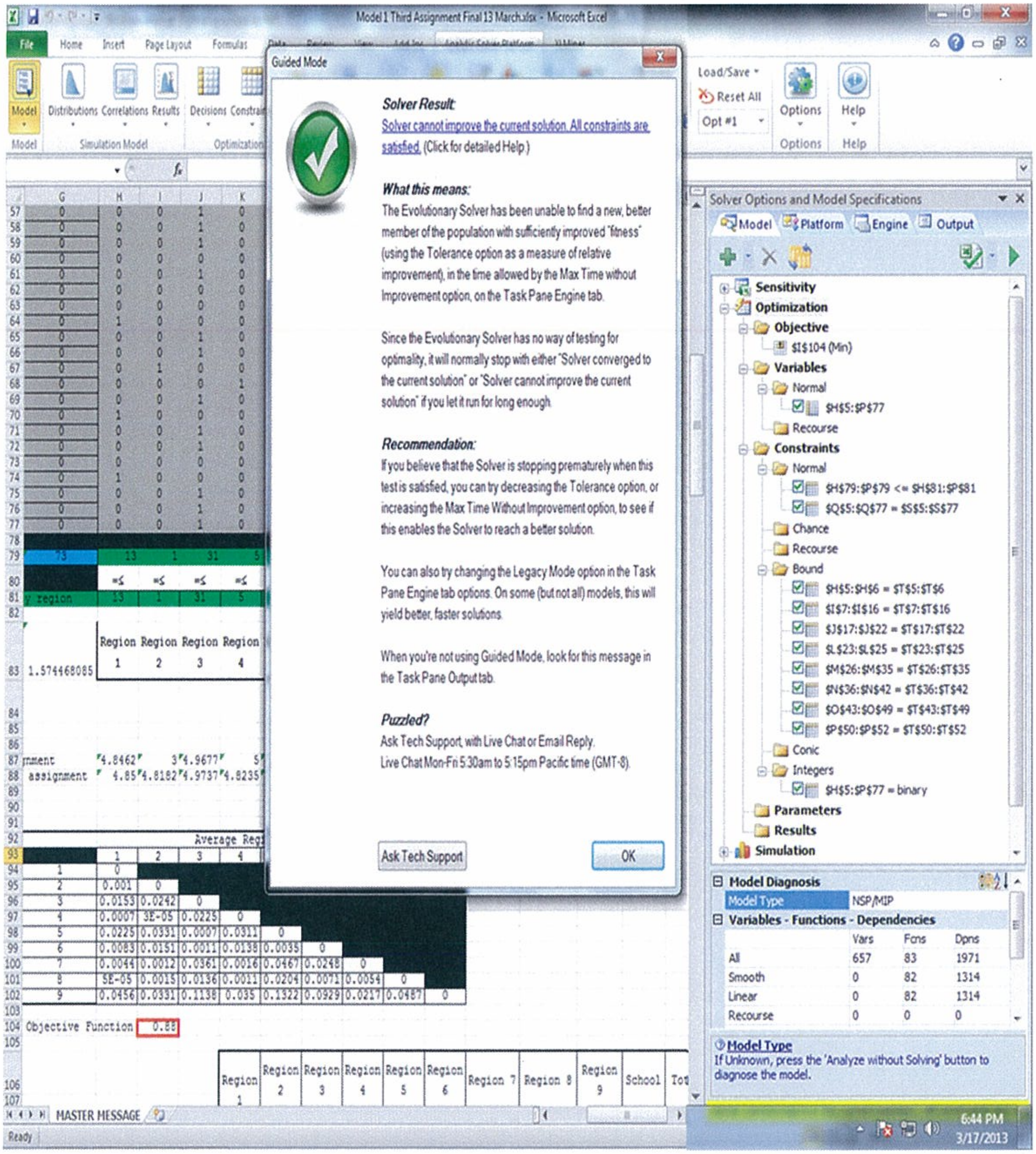
APPENDIX B: MODEL CONSTRAINT SETUP USING PREMIUM SOLVER PLATFORM



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